EFFECT OF POSTMORTEM BONING TIMES ON BEEF STORAGE QUALITY

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ABSTRACT

Measurements relating to appearance, bacterial populations, tenderness, and flavor were made on samples of longissmus dorsi muscle from matched hot boned and conventionally chilled halves of beef during 20 days of storage. Slower bacterial growth, higher tyrosine values, darker color, and higher creatine content were observed in hot boned meat than conventionally chilled meat throughout the storage period. Muscle fragmentation in hot boned meat increased during storage. Initially, hot boned meat had lower muscle fragmentation than did conventionally chilled meat, but by the end of storage the muscle fragmentations were approximately equal for both treatments. Creatinine and pH were approximately equal for both treatments.

INTRODUCTION

HOT BONING of beef is an energy saving technique for the meat processing industry. Henrickson (1975) estimated that up to a 30% reduction in energy requirements per carcass is possible if beef is boned before chilling. Various conditioning regimes have been used by investigators to prevent deleterious changes (mainly cold shortening) in hot boned beef. Schmidt and Gilbert (1970), Follett et al. (1974), Schmidt and Keman (1974), Heinz et al. (1975), and Dransfield et al. (1976) conditioned the beef after boning by holding it at temperatures varying from 5–15°C for 4–48 hr. Kastner et al. (1973, 1976), Kastner and Russell (1975), Falk et al. (1975) and Will et al. (1976) conditioned the carcasses before boning by holding them at 15°C for 2–10 hr before boning.

These investigators compared hot boned beef with conventionally boned beef (beef boned after chilling). They measured tenderness, juiciness, texture, flavor, bacterial load, shear, fiber diameter, color, cooking loss and % carcass yield at a specific time post slaughter. These properties were selected to detect changes in the meat quality caused by cold shortening and handling methods. If a conditioning regimen which prevented cold shortening were used, hot boned meat had essentially the same properties as conventionally treated meat. All experiments except those of Heinz et al. (1975) were designed to aid in determining the best conditioning regimen. Heinz et al. (1975) compared hot boned vacuum packaged meat with conventionally boned vacuum packaged meat after extremely long storage (4–6 wk). However, the changes in aerobically packaged hot boned beef during refrigerated storage periods of intermediate length (3–20 days) which affect the consumer appeal and ultimate eating quality of the meat have not been monitored.

Color values (Δ%R) and tyrosine values have been established as effective means of following bacterial contamination and determining changes occurring during storage (Strange et al., 1977). Reagan et al. (1975) reported significant correlations between muscle fragmentation index and Warner-Bratzler shear values; therefore, muscle fragmentation, calculated as % sediment, was used as an indication of tenderness. Creatine is correlated negatively with flavor and creatinine is correlated positively with flavor (Macy et al., 1970). Increased free tyrosine content has been associated with proteolysis during aging (Pearson, 1968), and creatine and pH are biochemical indicators of the rigor state of the meat (Bendall, 1973).

The purposes of our experiments were to compare the changes that occurred in hot boned meat with those in conventionally boned meat during refrigerated storage by monitoring quality factors correlated with changes in appearance, bacterial contamination, tenderness, and flavor of the meat. The factors, measured daily for 20 days, were: color, bacteria counts, pH, muscle fragmentation, creatine, creatinine and tyrosine content. Warner-Bratzler shear tests were carried out at selected times during the storage period.

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EXPERIMENTAL

THE LONGISSIMUS DORSI muscle was used in all experiments. Three choice grade steer carcasses were obtained from a local slaughterhouse. The longissimus dorsi was removed from one side of each carcass as soon as practicable after slaughter (average 40 min) and held at room temperature (20°C) for 4–6 hr until the muscle pH had fallen to 5.7. These hot boned (HB) muscles were then cut into 100g 2.5 cm thick steaks and wrapped in an oxygen permeable, water impermeable polyvinyl-chloride stretch film (MC-FMC). One sample was analyzed immediately and the rest were stored in the dark at 3°C, and sampled daily for a minimum of 20 days.

The other halves of the carcasses were conventionally chilled (CC) at 1–2°C in a packinghouse cooler and the longissimus dorsi muscles were removed 2, 3, or 4 days after slaughter. These CC muscles were packaged, stored, and sampled in the same manner as the HB samples.

Storage time for CC meat was calculated as days post slaughter (day 0, time frame A, being the day of slaughter) and days post packaging (day 0, time frame B, being the day the meat was boned and packaged). For HB meat, days post slaughter and days post packaging differed by only ¼ day and so were considered to be essentially identical.

The data for each determination from the analysis of three animals were combined and correlation coefficients and regression analysis were calculated for both HB and CC sides. Paired samples of HB and CC meat from the same carcass and stored the same number of days post packaging or post slaughter were used for analysis of differences.

Methods

Color. The color values, (%R 630 nm – %R 580 nm) or Δ%R, of the intact steak surface were determined daily according to the method of Strange et al. (1974) using a Beckman DBG recording spectrophotometer equipped with a diffuse reflectance attachment. Percent R 630 nm is a reflectance minimum of metmyoglobin and %R 580 nm is a reflectance minimum of oxymyoglobin.

Bacteria plate counts. Meat samples of known surface area (ca 60 cm^2) and weight (ca 50g) were prepared from the stored steaks by aseptic techniques. Each sample was weighed and surface area measured. These samples were shaken with sterile distilled water (4 ml water/cm^2 surface) in sterile quart Mason jars. Appropriate dilutions were made, spread on nutrient agar (three plates each), and incubated for 3 days at 20°C. Bacteria counts are reported as $\log_{10}$ per cm^2 of the actual count. Bacteria from selected colonies were characterized by standard bacteriological techniques.

pH and muscle fragmentation. A slurry was prepared by blending the meat (previously used for bacteria counts) with two times the sample weight of water in a Waring Blendor operated at high speed for 2 min. The pH of this slurry was measured with a combination probe glass electrode. An adaptation of a method described by Reagan et al. (1975) was used to determine muscle fragmentation and the results calculated as % sediment. The meat slurry was filtered throough a single layer of cheese cloth and the filtrate was centrifuged at 5000 rpm (ca 4000g) for 15 min in a 250 ml stainless steel centrifuge flask in a Servall SS-3 centrifuge. The supernate was poured off and the residue weight

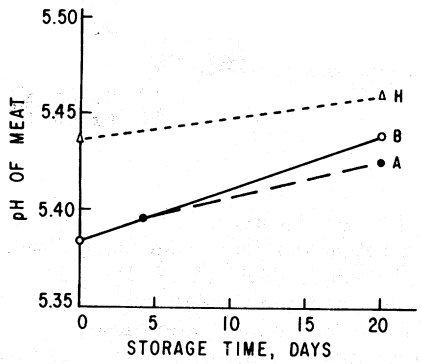

Fig. 1—Regression line of pH of meat versus days of storage: H—hot boned (slope = 0.001, r = 0.08); A—conventionally chilled from day of slaughter (slope = 0.002, r = 0.16); B—conventionally chilled from day of packaging (slope = 0.003, r = 0.23).

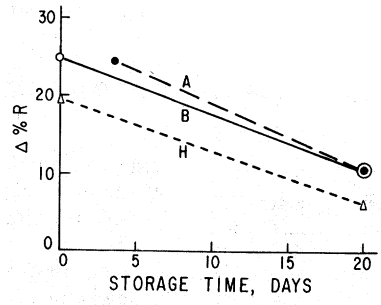

Fig. 2—Regression line of color value (Δ%R) of meat versus days of storage: H—hot boned (slope = −0.666, r = −0.67); A—conventionally chilled from day of slaughter (slope = −0.836, r = −0.76); B—conventionally chilled from day of packaging (slope = −0.831, r = −0.75).

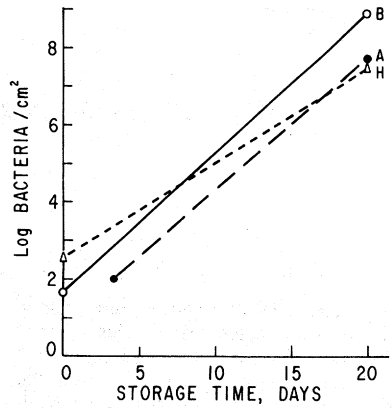

Fig. 3—Regression line of log bacteria/cm² in meat versus days of storage: H—boned (slope = 0.248, r = 0.73); A—conventionally chilled from day of slaughter (slope = 0.340, r = 0.82); B—conventionally chilled from day of packaging (slope = 0.361, r = 0.86).

was determined. Percent sediment (muscle fragmentation) was calculated as residue weight/sample weight.

Tyrosine, creatine and creatinine. Tyrosine, creatine, and creatinine levels were determined in a protein free trichloroacetic acid (TCA) extract of the meat prepared in the following manner. Twenty grams of meat were blended with 50 ml of cold 20% TCA for 2 min. The contents were removed, the blendor was rinsed with 50 ml of water, and the rinse was then combined with the TCA-meat mixture and filtered through a Whatman #1 filter paper.

Tyrosine value was determined by the method of Pearson (1968). Two and a half ml of the filtered TCA extract were diluted with 2.5 ml of water. Ten ml of 0.5N NaOH followied by 3 ml of Folin's reagent (diluted 1 part Folin's:2 parts water) were added to the extract. After mixing the color was allowed to develop for 15 min at room temperature and then read at 660 nm. Concentration of tyrosine was determined from a previously prepared standard curve. The tyrosine value is reported as mg of tyrosine/g of meat.

Creatine levels were determined on the filtered TCA extract by a modified method of Eggleton et al. (1943). The reagent was prepared immediately prior to use by mixing equal volumes of diluted diacetyl solution (Eggleton et al., 1943) and 1% α naphthol in 2N NaOH (Smith, 1960). One ml of a 1:99 dilution of the filtered TCA extract was mixed with 1 ml of the reagent, the reaction mixture was heated in an oven at 100°C for 10 min, and the absorbance was read at 550 nm. The absorbance of a reagent blank was determined daily. The diacetyl-α-naphthol reagent also reacts with creatinine and arginine under the conditions employed. The specific and molar extinction coefficients of the reaction mixtures for creatine, creatinine, and arginine were determined. Beer's Law applied in the range of concentrations used. Results are presented as mg of creatine/g of meat.

Creatinine levels were determined by use of a method described by Hawk et al. (1954) for determination of creatinine levels in blood. Five ml of 1:4 dilution of the filtered TCA extract were mixed with 2.5 ml of a freshly prepared alkaline picrate reagent (10 ml saturated picric acid + 2 ml 10% NaOH). Absorbance was read at 540 nm after 15 min. A blank was determined for each run, and the concentration of creatinine was read from a previously prepared standard curve. Results are presented as mg creatinine/g meat.

Warner-Bratzler shear test. Tests were run on raw meat and meat cooked to internal temperatures of 50°C and 60°C. Four 1-in. cores were sheared across the grain twice for each temperature for a total of eight shear values for each temperature. Warner-Bratzler measurements were run on meat aged 9, 10 and 11 days after slaughter.

RESULTS & DISCUSSION

THE HOT BONED MEAT was stored at 20°C until its pH dropped to 5.7. Bendall et al. (1976) indicated that cold-shortening in beef longissimus does not occur if the pH is below 6.0. After the meat was packaged and chilled overnight at 3°C, the pH dropped to an average of 5.4. The pH of HB and CC meat (post slaughter and post packaging) had no significant correlation with time of storage. The linear correlation coefficient (r) for the pH of HB meat versus storage time in days, for the pH of CC meat versus storage time in days post slaughter, and for the pH of CC meat versus storage time in days post packaging were not significant (Fig. 1). The differences between the slopes of the pH regression lines for HB and CC post-slaughter and post-packaging meat were not significant ($P < 50\%$) (Fig. 1), and the mean differences between pH's of HB and CC meat were not significant ($P < 99\%$) (Table 1).

Meat color is dependent upon the quantity and oxidation state of the muscle pigment myoglobin. Oxygenation of the purple myoglobin to bright red oxymyoglobin, or "bloom," occurs when fresh meat surfaces are exposed to air and is maximal after 24 hr exposure at 0°C. The formation of the undesired brown oxidized metmyoglobin on the surface results mostly from bacterial action but may be caused by long-term exposure to oxygen or by a coupled lipid oxidation mechanism (Benedict et al., 1975). The color value, Δ%R, is a measure of consumer preference for meat color and is related to the ratio of metmyoglobin to oxymyoglobin. The larger the Δ%R, the more acceptable the meat color. Conclusions about differing color values were based on the differences between HB meat and CC post-packaging meat (Table 1).

Color values were consistently lower for HB meat than for CC meat (Fig. 2). A darker color for HB meat was noted by Heinz et al. (1975) only after the meat had been severely cold shortened, and by Kastner et al. (1973) only with a 2-hr conditioning period. Kastner and Russell (1975) found the HB meat conditioned for periods of 8 and 10 hr had a lower ΔL (brightness) than CC meat. Darkening of hot boned meat has been ascribed by Heinz et al. (1975) to shortening of the muscle fibers. We did not measure sarcomere lengths but we assumed that our hot boned meat had shorter fibers since it entered rigor after the muscles were detached from the bone.

The correlation coefficients for days of storage versus color values were significant for both HB and CC meat (Fig. 2). The color value of the HB meat decreased less rapidly during storage than that of the CC meat. This difference between the slopes of the color regression line for HB meat and CC post-packaging meat ($t = -1.22$, $N = 119$) was significant at the 75% confidence level and may be due to the slower growth of meat spoilage organisms noted with HB meat.

A major limiting factor in meat storage is the surface bac-

terial load. The initial bacterial contamination (both type and numbers) affects the stability of the meat during storage. Most bacterial growth takes place on the surface of the meat, and cutting spreads bacteria from the exterior of the carcass to the freshly exposed surfaces. Conclusions about differing bacterial levels and growth rates in HB and CC meats are based on data from CC post-packaging meat.

At the time of packaging of the meat, bacteria counts were slightly higher for HB meat than for CC meat; however, after 10 days of storage they were higher for the CC post-packaging meat (Fig. 3). Early in the storage period, the bacteria on HB meat were a heterogeneous mixture of presumably mesophilic types (catalase +, gram +, cocci) which do not grow well at refrigerator temperatures. As storage time increased, these bacteria were replaced by the usual meat spoilage organisms (gram −, catalase +, short rods with characteristic pseudomonads odor). The bacteria on the CC meat at time of packaging were the pseudomonad type. The difference between the slopes of the log bacteria regression line for HB and CC post-packaging meat ($t = 2.73$, $N = 124$) was significant ($P > 99\%$). The difference in the type of bacterial populations at the time of packaging may account for the observed difference in the bacterial growth rates for CC meat and HB meat. Both HB and CC meat had approximately equal overall bacterial numbers (Table 1).

Two types of tenderness indicators, muscle fragmentation and the Warner-Bratzler shear test, were used to evaluate the differences between HB and CC meat. The initial muscle fragmentation of HB meat was much lower than that of CC meat (Fig. 4). However, the actual difference decreased daily until the muscle fragmentation of HB meat approximately equaled that of CC meat by 14 days after slaughter (Fig. 4). The mean differences between Warner-Bratzler shear test on HB and CC treated meats were not significant and are omitted ($t = 1.89$, $N = 41$, for meat heated to 60°C). These tests were run on meat samples 9, 10, and 11 days post slaughter. Schmidt and Gilbert (1970), Kastner et al. (1973), Falk et al. (1975), and Will et al. (1976) noted no important differences in tenderness for HB meat compared with meat from CC carcasses 48 hr post slaughter. Only one of our CC carcasses was evaluated at 48 hr post slaughter. In this case there was a difference of 0.8% sediment between the CC and HB meat compared to an average difference of 11% sediment for the first 10 days after slaughter for the other two carcasses. Schmidt and Keman (1974), Dransfield et al. (1976), and Follett et al. (1974) compared the tenderness of HB and CC meats at 8, 10, and 12 days post slaughter. Any significant tenderness difference between HB and CC meat would have disappeared because of the tenderization that occurred during the prolonged aging of the hot boned meat. Our Warner-Bratzler data agree with their findings. The correlation coefficient for days of storage for HB meat versus muscle fragmentation (% sediment) was significant ($P > 99\%$), but the correlation coefficients for days of storage for CC post-slaughter and post-packaging meat were not (Fig. 4). The difference between the slopes of the muscle fragmentation (% sediment) regression lines for HB meat and for CC post-slaughter meat ($t = 1.80$, $N = 126$) was significant at the 92% confidence level. Mean differences in muscle fragmentation for HB and CC meat were not significant ($P < 99\%$) throughout the storage period (Table 1); but, if only the first 10 days after slaughter were considered, the mean differences are significant (mean difference = −11.3%, $t = -3.04$, $N = 24$, $P > 99\%$). Tenderization took place more slowly in HB than in CC meat; CC meat was almost as tender at four days post slaughter as it was at 20 days post slaughter.

Tyrosine levels for HB and CC meat were approximately equal at the start of storage but increased faster in HB than in CC meat (Fig. 5). The correlation coefficients for days of storage versus tyrosine levels were significant ($P > 99\%$) for both HB and CC meats (Fig. 5). The differences between the slopes of the regression lines for HB and for CC post-slaughter ($t = 2.70$, $N = 129$) and for CC post-packaging ($t = 2.75$, $N = 129$) meats were significant ($P > 99\%$) and the mean differences (Table 1) were also significant ($P > 99\%$). Tyrosine levels are affected by the bacterial population as well as by length of storage (Strange et al., 1977), but the HB and CC meats had approximately equal bacterial populations (Table 1) and storage times.

Creatine content has been adversely related to flavor development (Russell and Baldwin, 1975). Creatine levels were consistently higher for HB meat than for CC meat (Table 1). The method used to measure creatine levels also detects arginine and creatinine under the conditions employed. The ratio of the molar extinction coeficients of creatine to either arginine or to creatinine was 5. The increased difference in creatine with time of storage may to a small extent be from arginine which is present in protein free extracts of meat at approximately 1.6 times the level of tyrosine (Field and Chang, 1969). Arginine could thus account for only 10% of the observed difference in creatine levels in HB meat. The correlation coefficients for the day of storage versus creatine levels were not significant for either HB or CC meats (Fig 6). The difference in these creatine levels apparently increases during storage (Fig. 6), but the differences between the slopes of the creatine regression lines for HB and for CC post-slaughter ($t = 0.76$, $N = 129$) and for CC post-packaging ($t = 0.60$, $N = 129$) meats were not significant.

Normal transformation of the muscle creatine to creatinine continues after slaughter and appears to be unaffected by processing. Creatinine levels for HB and CC post-slaughter meats were approximately equal throughout the storage period (Table 1). The differences between the slopes of the creatinine regression lines for HB and for CC post-slaughter ($t = -0.62$, $N = 125$) and post-packaging ($t = -0.70$, $N = 125$) meats were not significant ($P < 50\%$). The correlation coefficients for day of storage versus creatine content were significant ($P > 99\%$) for HB and CC meats (Fig. 7). Creatinine increased during storage as expected and was significantly related to time of storage.

Table 1—Comparison of hot boned and conventionally chilled meat throughout storage for three animals

	Paired sample differences of hot boned[a] and conventionally chilled meat					
	Time frame A[b]			Time frame B[c]		
Tests	Mean difference	t	N	Mean difference	t	N
Color value (Δ%R)	−5.535	−6.24**	57	−4.77	−4.91**	53
Log bacteria/cm²	0.54	2.62*	60	−0.16	−0.83	58
pH	0.02	2.20	56	0.03	2.01	52
% Sediment	−4.01	−1.61	59	−4.70	−1.39	56
Tyrosine, mg/g	0.19	9.05**	60	0.10	4.23**	59
Creatine, mg/g	0.45	2.84*	60	0.43	2.25	59
Creatinine, mg/g	−0.0004	−0.06	60	−0.0165	−2.23	59

[a] Packaged on day of slaughter
[b] Conventionally chilled meat boned and packaged 2, 3, or 4 days after slaughter, time dated from slaughter
[c] Conventionally chilled meat boned and packaged 2, 3, or 4 days after slaughter, time dated from packaging
** $P > 99.9\%$ that the mean difference is significant
* $P > 99\%$ that the mean difference is significant

CONCLUSION

HOT BONED (HB) MEAT compared with conventionally chilled (CC) meat early in the storage study had lower color values and muscle fragmentation; equivalent pH, free tyrosine, and creatinine levels; and higher bacteria counts and creatine

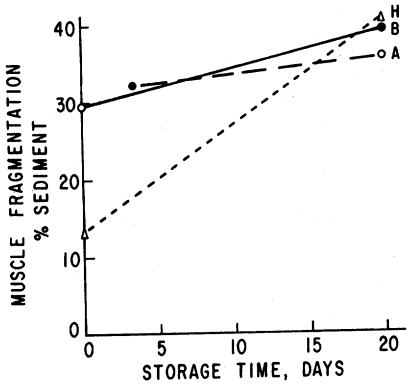

Fig. 4—Regression line of % sediment of meat versus days of storage: H—hot boned (slope = 1.374, r = 0.40); A—conventionally chilled from day of slaughter (slope = 0.218, r = 0.05 (not significant at P > 99%)); B—conventionally chilled from day of packaging (slope = 0.486, r = 0.12 (not significant at P > 99%)).

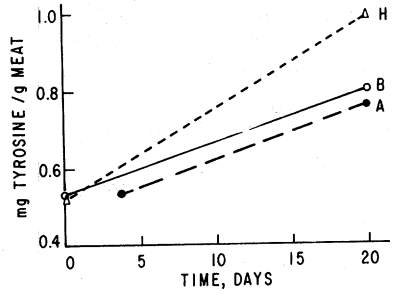

Fig. 5—Regression line of tyrosine mg/g in meat versus days of storage: H—hot boned (slope = 0.023, r = 0.75); A—conventionally chilled from day of slaughter (slope = 0.014, r = 0.68); B—conventionally chilled from day of packaging (slope = 0.014, r = 0.66).

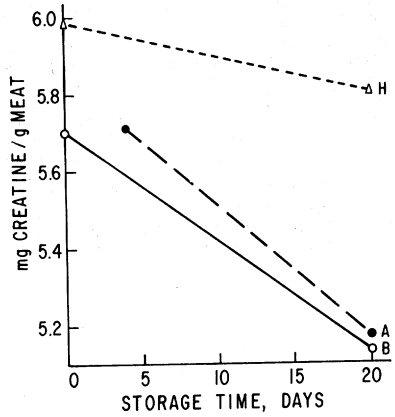

Fig. 6—Regression line of creatine mg/g in meat versus days of storage: H—hot boned (slope = −0.009, r = −0.05 (not significant at P > 99%)); A—conventionally chilled from day of slaughter (slope = −0.034, r = −0.17 (not significant at P > 99%)); B—conventionally chilled from day of packaging (slope = −0.029, r = −0.14 (not significant at P > 99%)).

levels. After storage, HB meat had lower color values and bacteria counts; equivalent pH, creatinine, and muscle fragmentation; and higher free tyrosine and creatine levels. During storage creatinine and pH of HB and CC meats were equivalent; free tyrosine and creatine contents were consistently higher in HB than in CC meat; the color values were consistently lower in HB than in CC meat; muscle fragmentation in HB was lower than in CC early in storage but rapidly increased to equal CC meat by 14 days after slaughter. Bacteria counts increased more slowly on HB than on CC meat.

HB meat reacts differently to storage than does CC meat. Hot boning results in a darker meat color throughout the storage. The bacteria counts on HB meat are higher initially, but during storage bacterial growth is slower on the HB meat, which may increase shelf life of HB meat. Initially, HB is tougher than CC meat, as measured by % sediment, but by 10 days post slaughter there is no difference in Warner-Bratzler shear tests. The higher tyrosine content of HB meat suggests that this tenderization in the HB meat is due to a proteolysis during aging. CC meat having a lower tyrosine content apparently does not undergo this type of additional tenderization. The higher creatine content of HB meat could adversely affect flavor, but the effect of hot boning on flavor needs more study. Hot boning has no effect on the ultimate pH and the creatinine content of the meat during storage.

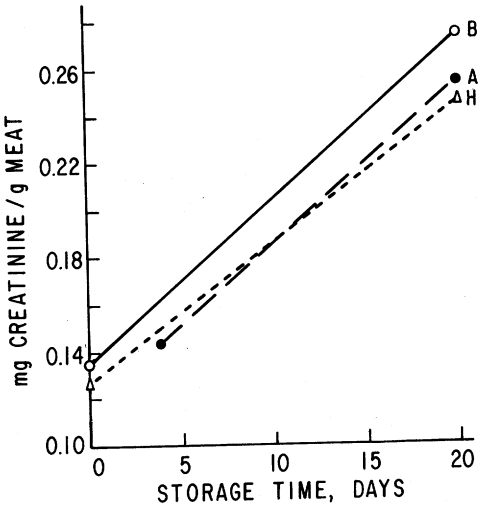

Fig. 7—Regression line of creatinine mg/g in meat versus days of storage: H—hot boned (slope = 0.006, r = 0.66); A—conventionally chilled from day of slaughter (slope = 0.007, r = 0.60); B—conventionally chilled from day of packaging (slope = 0.007, r = 0.60).

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